## MODIFICATION AND EVALUATION OF ELASTOMER
## TEST MACHINE (ETM)

U.S. ARMY - ERO CONTRACT NO.

DAJA45-88-C-0038

R&D 6101 - MS- 01
FINAL REPORT :   JANUARY 1991

D.K. Das-Gupta
SCHOOL OF ELECTRONIC ENGINEERING SCIENCE
UNIVERSITY OF WALES, BANGOR
DEAN STREET
BANGOR
GWYNEDD  LL57 1UT
U.K.

Telephone: (0248) 351151 Ext: 2696/2690
Fax: (0248) 361429
Telex: 61100 UCNWSL G

Accession For

A&..' GRA&I
D1... TsB
Announced
Justification

By
Distribution/
Availability Codes
Avail and/or
Dist   Special
A-1

# INDEX

(i)

**TABLES:**

# REPORT DOCUMENTATION PAGE

| 1a. REPORT SECURITY CLASSIFICATION<br>Unclassified | 1b. RESTRICTIVE MARKINGS |
|---|---|
| 2a SECURITY CLASSIFICATION AUTHORITY | 3 DISTRIBUTION / AVAILABILITY OF REPORT<br>Approved for public release; distribution unlimited |
| 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE | |

| 4 PERFORMING ORGANIZATION REPORT NUMBER(S) | 5. MONITORING ORGANIZATION REPORT NUMBER(S)<br>R&D 6101-MS-01 |
|---|---|

| 6a NAME OF PERFORMING ORGANIZATION<br>University College of<br>North Wales | 6b. OFFICE SYMBOL<br>(If applicable) | 7a. NAME OF MONITORING ORGANIZATION<br>European Research Office<br>USARDSG-UK |
|---|---|---|
| 6c. ADDRESS (City, State, and ZIP Code)<br>School of Electronic Engineering Sciences<br>Dean Street, Bangor,<br>Gwynedd, LL57 1UT, Wales, UK | | 7b ADDRESS (City, State, and ZIP Code)<br>Box 65<br>FPO NY 09510-1500 |
| 8a NAME OF FUNDING / SPONSORING<br>ORGANIZATION  USARDSG-UK<br>European Research Office | 8b OFFICE SYMBOL<br>(If applicable) | 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER<br>DAJA45-88-C-0038 |

| 8c. ADDRESS (City, State, and ZIP Code) | 10 SOURCE OF FUNDING NUMBERS | | | |
|---|---|---|---|---|
| Box 65<br>FPO NY 09510-1500 | PROGRAM ELEMENT NO<br>61102A | PROJECT NO<br>1L161102BH57 | TASK NO<br>04 | WORK UNIT ACCESSION NO |

11 TITLE (Include Security Classification)

(U) Modification and Evaluatiob of Elastomer Test Machine (ETM)

12 PERSONAL AUTHOR(S)
Dr. D.K. Das-Gupta

| 13a TYPE OF REPORT<br>Final | 13b TIME COVERED<br>FROM 9.23.88 TO 9.23.90 | 14 DATE OF REPORT (Year, Month, Day)<br>91.3.2 | 15 PAGE COUNT<br>29 |
|---|---|---|---|

16 SUPPLEMENTARY NOTATION

| 17 | COSATI CODES | | 18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number) |
|---|---|---|---|
| FIELD | GROUP | SUB-GROUP | |
| | | | |
| | | | |

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The Elastomer Test Machine (ETM) which was constructed under Contract No. DAJA 45-85-C-0044 in May 1988 has been modified to include synchronization of the linear table with the 'Ram Action' of the press, a new linear Model 2, measurement of the horizontal force of the sample and a slip ring system for the measurement and control of temperature. The Elastomer samples can now be tested at different temperatures (>140°C) in the stationary impact mode, in two linear abrasion mode and in a rotational mode (and combinations thereof). Temporal qualitative data on load and displacement can be recorded which may provide a qualitative analy of the elastomer degradation processes.

A comprehensive set of test data were obtained with the ETM using all the modes for 57 different elastomer samples, provided by the US Army (51 samples) and the US Navy (6 samples). The ETM tests provide a performance analysis of any track pad elastomer material and may predict a projected service life.

| 20 DISTRIBUTION / AVAILABILITY OF ABSTRACT<br>☒ UNCLASSIFIED/UNLIMITED  ☒ SAME AS RPT  ☐ DTIC USERS | 21 ABSTRACT SECURITY CLASSIFICATION<br>Unclassified |
|---|---|
| 22a NAME OF RESPONSIBLE INDIVIDUAL<br>Dr. W.C. Simmons | 22b TELEPHONE (Include Area Code)<br>071 409 4423/4485  22c OFFICE SYMBOL<br>AMXSN-UK-RM |

**DD FORM 1473, 84 MAR**  83 APR edition may be used until exhausted  SECURITY CLASSIFICATION OF THIS PAGE
All other editions are obsolete

# ABSTRACT

The Elastomer Test Machine (ETM) which was constructed under Contract No. DAJA 45-85-C-0044 in May 1988 has been modified to enhance the capabilities and, therefore, its performance. The capabilities of the machine are reflected by the number of different 'MODES' of operation which have access through the ETM control panel. Elastomer samples can now be tested at different controlled temperatures not exceeding $140^\circ C$ in the following 'MODES':

(i)     Stationary sample mode (single impact and autocycle multiple impact);

(ii)    Rotating sample mode (single impact and autocycle multiple impact);

(iii)   Linear Mode 1:
        Tool bit is embedded in the sample to a preset depth. The linear movement of the sample, back and forth, generates a highly abrasive condition.

(iv)    Linear Mode 2:
        This mode is an extension of the linear mode 1 in which the sample linear movement is synchronised with the press ram stroke such that the tool bit is embedded during our traversal of the sample and then raised whilst the sample traverses in the opposite direction. At the extreme displacement of the sample table, the tool bit is lowered again for another cycle with continuous repetition. The ETM provides temporal data for quantitative load and displacement which may be used for quantitative analysis of the degradation process.

Fifty seven elastomer samples have been tested in the linear and rotational modes including the six round robin (US Navy samples). The results provide not only sufficient confidence in the operation of the ETM but also assess the nature of aging following a standard code of test procedure.

## 1. INTRODUCTION

Present report provides a description of the modification of the Elastomer Test Machine (see Final Report ERO Contract No. DAJA 45-85-C-0044). It also gives an analysis and correlation of test data for track pad material provided by the Materials Technology Laboratory, Watertown, M.A., using the modified Elastomer Test Machine (ETM). Elastomeric materials, provided by the Department of the Navy (USA) were also tested by the ETM in a multi-laboratory testing programme and an evaluation of such data is also provided in this report.

## 2. MODIFICATION OF THE ELASTOMER TEST MACHINE

An Elastomer Test Machine (ETM) was designed and constructed at the School of Electronic Engineering Science, University of Wales Bangor (see Final Report: Contract No. DAJA 45-85-C-0044). The ETM can apply stresses to elastomers in a controlled and observable manner, thereby providing information on comparative performance and aging of such materials under test. Only a brief description of the ETM will be given here as it has already been described in detail in the Final Report of the Contract No. DAJA 45-85-C-0044.

The ETM consists of a six ton half body press, manufactured by Rother Machine Tools Ltd., and the major constituent parts of the system are as follows:

### (2.1) RAM PRESS

The pneumatic ram press operates with an air supply of 80 p.s.i. pressure. The vertical impact of the ram causes a tool bit (figure 2) to impinge upon the surface of an elastomer sample, mounted on the test bed. The ram can operate both in a single shot mode or in an autocycle mode. In either mode the machine can be stopped by raising the protective transparent guard. A load cell pressure transducer, located appropriately above the tool bit detects the vertical loading.

### (2.2) SAMPLE HOLDER & STAGE

The sample holder consists of a nickel plated copper block which houses a $63.5 \times 63.5 \times 16mm^3$ block of the material under test. The copper block accommodates two 100 watt cartridge heating elements along with a J-type thermocouple sensor. The block temperature can be controlled upto $200^oC$ using an Eurotherm Model 820 temperature controller which is set by push button controls on the instrument facia.

The sample holder may be located horizontally or at an angle of $> 30^o$ from the horizontal direction (TILTED MODE). It may also be rotated (ROTATIONAL MODE) or operated in a LINEAR CYCLIC MODE. For the last two modes the sample is located horizontally. These three modes are in addition to the STATIONARY MODE.

### (2.3) DATA ACQUISITION AND OPERATION

The outputs from the load cell and temperature transducers are fed into a display unit and also to a CIL Microsystems PCI 6380 interface and a Personal Computer via a General Purpose Interface Bus (GPIB).

4

## (2.4) MODIFICATION

The following modifications were incorporated in the existing ETM, constructed with the funding provided by the ERO (Contract Number DAJA 45-85C-0044) to improve its usefulness and performance.

(i)        Synchronization of the Linear Table with the 'Ram Action', of the Press.

(ii)       New Linear 2 Mode.

(iii)      Measurement of the 'Horizontal Force' on the sample.

(iv)      Slip-Ring System for the measurement and control of temperature.

The synchronization of the linear table with the press ram stroke was achieved by installing a dummy cylinder with its magnetic piston coupled to the linear table (figure 1). The linear movement of the table moves this piston whereby its inbuilt magnet activates the proximity switches set at any selected position within the range of travel. The two proximity switches, in turn, control the power to energise the solenoid operated pneumatic valves to raise or lower the press ram. This arrangement, therefore, couples directly the sample's linear position with the point of entry and the withdrawal of the Ram/Tool bit. This is now known as Linear Mode 2.

This new Linear 2 Mode is an extension of the original linear mode for which the tool was permanently embedded. In this mode the ram impacts with the sample, the tool bit remaining embedded for one traversal of the table. The ram is then automatically raised whilst the traversal of the table continues in the opposite direction. At the extreme displacement of the table the tool bit is lowered again by the ram, initiating another impace drag cycle. This is repeated continuously and it leads to eventual tearing with debris being accumulated at one edge of cut produced. Linear 2 Mode enables vertical impact damage and linear mode damage to be inflicted on the sample under test.

Two further load cells (RDP Electronics Ltd) have been incorporated in a modified tool bit holder (figure 2). With the positions, shown in figure 2, when the tool bit is embedded in a sample and with a linear movement applied in either direction, the sample resistance is transmitted directly to each load cell which has a full scale calibrated capacity of 500lb.

Silver-Graphite brushes have been installed with silver plated slip rings. This arrangement ensures good stability of contact resistance over a long period of time and this provides an accurate control of the sample temperature within $\pm 1^{0}C$ at temperatures not exceeding $140^{0}C$ which is set by a push button control on the Eurotherm Controller.

One other item has also been incorporated in order to conform to the Health & Safety at Work Act U.K. (1974) namely that the airpress control system have had a safety modification kit installed to the makers instruction. This brings the press up to the present safety standards of the U.K.

## 3. TEST MODES

**(i)     Vertical Impact Test:**

**Stationary Mode.**

In this mode the ram drives up and down on the sample for a required number of impacts, say 500 or for a set time.

The stationary mode may also be used in conjunction with the sample being located at a tilt angle (Tilt Mode). The tilting of the table, of course, inhibits any movement of the test bed.

**(ii)    Abrasion Test:**

**Linear Mode 1.**

Here the platform moves linearly forward and back in a horizontal plane at a set rate. The tool may be permanently embedded in the sample causing abrasion and eventual erosion.

**Linear Mode 2.**

In this case after each traversal in one particular direction, the embedded tool bit may be raised by the ram for the duration of the return traversal, the tool being ready to impact at the beginning of the next cycle. This process in then repeated automatically.

In both the linear modes the testing occurs for a set time, typically several minutes or for a registered number of impacts for the Linear Mode 2 only.

**(iii)   Rotational Mode (Radial Rotational Wear)**

In this mode, the tool bit is embedded in the centre of the sample and the table rotates at a frequency set by the operator. Alternatively, the ram can be set to impact repeatedly on the sample as the sample rotates (i.e., auto/cycle mode).

## 4. DATA ACQUISITION OF ETM

The outputs from the Eurotherm Model 820 temperature controller and the three load cells are fed into digital display units which form a composite block. The signals from the display units are also fed into a CIL Microsystem PCI 6380 Microcomputer Interface and into a Personal Computer via a General Purpose Interface Bus (GPIB). The Data acquisition and start/stop operations are provided on the ETM by an IBM PC Computer (figure 3).

The CIL Microsystem PCI 6380 has four output channels, four relays, eight input channels and a 15-bit digital output from the rear panel. It has internal software consisting of 4K bytes on EPROM, 6K bytes of RAM, of which 4K is user accessible. The output from the temperature controller and the three load cells are fed into channels 10, 11, 12 and 13 respectively. One of the Relay channels 'RO' is used for starting and stopping the ETM via the computer keyboard.

The GPIB has its own Z80 microprocessor and operating software, upto 40K

bytes of RAM being available. A BASIC Program enables the acquisition of the data.

The complete system is microprocessor controlled.

A video guide for the operation of the ETM, together with the Instruction Manual are available for training of the personnel in the operation of the ETM.

## 4. SPECIFICATION OF THE ELASTOMER TEST MACHINE

(i)     Electricity Supply:   110 volts at 60Hz.

(ii)    Air Pressure:   80 p.s.g. max.

(iii)   ETM is free standing on its own plinth. The motive power for the impacting of the samples is generated by an air operated "Toggle" press capable of supplying 6 tons maximum force in either single impact or continuous cycle modes (selectable). Both the tonnage and the stroke or adjustable.

A separate supply of 80 p.s.g. is required to operate the linear oscillating mode. The ram head has a facility for selection from different blade forms to apply differing cut characteristics to the sample.

(iv)    Modes.

A sample can be tested in four modes with reference to the line of impact and these are as follows.

Vertical Impact Test:          Single or Continuous.
Rotational Mode:               3 rev/sec max.
Linear Modes 1 & 2:            up to 2" max.
Tilt Mode:                     30 degrees from horizontal.

(iv)    Impact.

Force upto 5000 lbs max. (load cell max)
Frequency (proportional to
the stroke length):           1-4 per sec.
Cycle:                         single or continuous.
Sample Penetration Depth:      15mm max.

(v)     Sample.

Size:                          4" x 4" x $2\frac{1}{2}$" thick max.
Temperature:                   Room temperature to $140^{\circ}C$.

## 5. AGING BEHAVIOUR OF TEST SAMPLES:   RESULTS & ANALYSIS

A comprehensive set of test data were obtained with the ETM using all the modes for 57 different elastomer samples, 51 samples being provided by the U.S. Army (MTL - Watertown, MA.) and the remaining six belonging to the

U.S. Navy (Dahlgren, VA.). The Navy samples have also been tested for the TTCP round robin programme organized by Dr. Bruce Hartman of the Naval Surface Warefare Centre (Dahlgren, VA.). The aim of the tests carried out with the ETM is to give a performance analysis of any track pad elastomer and to predict in comparison with other similar materials, a projected service life.

All testing was conducted at $60^{0}$C for seven minutes for each sample which was weighed prior to testing and again after testing to determine the weight loss. The variation of load was monitored for each test and the level of deterioration established as a percentage. The relative performances have been assessed with respect to the weight loss and the percentage load depreciation and the results have been tabulated in an expected order of overall durability for both the Army and the Navy elastomer materials.

Figure 4, 5 and 6, show the typical recorded plots of the abrasion test in the LINEAR MODE 1 for the elastomer samples 15TPU, MB2690 and 15TP-1417X respectively, the test running in each case for 7 minutes. These recorded traces have several salient features which are as follows. The graph for loading has two visible parts for each load cell plots of the side to side thrusts. These consist of a first shoulder preceding a second peaked shoulder. The relative prominence of the first shoulder and the peak change with time during the course of the LINEAR MODE test in which the first shoulder rounds off and decreases in height where as the second peak is seen to increase in prominence, although its overall height often is observed to decrease. Between the shoulder and the peak an inflexion is observed where a peak begins to form. This location has been used as a measure of the values of the load for the reason explained in the following observation.

It was observed that as the tool bit traversed across the sample debris accumulated at the extreme points of the tool travel. It is suggested that this was responsible for the creation of an additional resistance pad which increased the magnitude of the load displayed at these positions, and hence a possibly exaggerated peak. The first traversal (forward and return) of the tool bit induced comparatively higher loads than at any other time in the linear mode testing. This phenomena can be seen at the beginning of the plots of the first minute of the test with a sample. The load is observed to decrease to lower values during the successive traversals. It is thought that the first travel breaks down the surface resistance and softens the material to a certain degree. The 'stress relaxation' may also occur in the process of the lowering of the measured load as the experiment progresses. however, the stress relaxation is known to occur under a static load. The load depreciation during the test run was thus due to the breaking up of the sample surface. In general, where a damage occurred in the sample, the form of the chart recorder trace at the beginning of the test run differed in size from that towards the end of the test run, the latter being reduced with sharper peaks.

The schematic representations in figures 7 and 8 show the forms of the output obtained from the recorded trace. Figure 7 shows the behaviour of a relatively soft sample whereas figure 8 represents a typical nature of load behaviour for a hard sample. The first shoulder, and the oncoming peak are denoted by A and B respectively in figures 7 and 8 from which it may be observed that the initial shoulder becomes rounded and diminishes whereas the peak becomes more pronounced with time, although its magnitude

8

may reduce. The level of the inflexion between the two humps also decreases with time as the sample cuts and breaks apart.

Another interesting aspect of the chart recorder traces, obtained with the harder samples can be explained in terms of crack-development under loading. A fracture of thermosetting polymers such as epoxies (LORD and XPE - series) strongly depend on the test temperature and the loading rate. AT low temperatures and high loading rates the crack growth is brittle. At intermediate temperatures and loading rates a fracture tends to be discontinuous (stick/slip process). This was thought to be the situation in the case of the linear mode testing at $60^{\circ}$C for such XPE 10 and LORD 4608-62 developed high loading to > 200 lbs. The damage incurred was very dynamic and vigorous with some particles of debris travelling short distances when dislodged.

A typical load-time curve during crack growth for an epoxy specimen is shown in figure 9. The crack grows for a while with falling load until it arrests. This is known as stick-slip growth. The initial crack growth requires a larger load than to propagate the crack.

Three patterns of load variations were observed in the linear mode for the elastomers tested in this work. These are as follows:-

(i)     The load will begin at a high value, for example 59 lbs for the sample 15TPT and then, as cutting/chauking is initiated, loading would begin to decrease, reaching a low value of 31 lbs.

(ii)    The load will begin at a very low level for exceptional samples, such as A8-MOCA and AM-CYAN 85-69. No damage will be observed except for a slight marking of the materials surface. At the end of the test run, the load will still be very low. However, after a time equivalent to three or four test runs (21-28 minutes) damage will occur when the final result will be equivalent to the tear damage observed in poorer samples. At the onset of damage the load was observed to increase first before decreasing, for samples in this category.

(iii)   For samples which initially displayed a high loading (> 150 lbs), the load was seen to be increasing at the end of the test run. For this third category, care was taken not to confuse the reading with the peak due to debris formation. Some of the Army samples, where a greater range of compounds were tested, fall into this category.

The HARDNESS of the samples was obtained from the value of loading over the first traversal in the linear test. This value, in pounds (lb), was obtained by averaging the reading for both the left and the right load cells. A hard material may be expected to be brittle.

With the ROTATIONAL MODE the vertical load deterioration was reliably monitored at 30 seconds intervals, and graphs of load against time provide useful comparison of weight loss for samples. Figures 10 and 11 for example, show typical weight loss behaviour with time for sample 37721C (most resilient) and sample NSWC17 (least resilient).

It was noted that the vertical load measured by the E-307-2 would gradually decrease after the ram was brought down with the tool positioned

9

in the sample, the deterioration amounting to a few pounds (lbs). This was thought to be solely due to stress relaxation in the material. However, once the rotation of the platform was started, deterioration was observed to be quite fast and considerable.

The horizontal loading in the rotational mode was found to be constant, its numerical value being different for each material. It should be noted that when the platform rotates in a given direction, only one of the load cells will show a useful load reading and this occurs at a time during the rotation when the tool is caused to pivot into that load cell.

Initial loading in the rotational test can also serve to determine the hardness. Thus, for both the linear and the rotational modes the ETM w'll function as a DUROMETER, a device specifically designed to measure the hardness of rubber.

The greatest source of potential error probably lies in the initial setting and subsequent maintaining of sample cut depth. To this end, such settings are now carried out on the ETM by using an inbuilt LVDT instrument with its calibrated display unit where accurate monitoring of cut depth is simply achieved.

The results of the tests for the Army (MTL) samples are shown in the Tables 1-5 which similarly the measured data for the Navy samples are shown also in appropriate orders in Tables 6-10.

## 6. CONCLUSION

A standard testing procedure has been developed with the ETM by experimenting with the Navy and the Army elastomer samples. Overall, the results are encouraging and give credence to the various modifications which have been implemented on the ETM which is easy to operate and gives reproducible results.

## 7. REFERENCE

E. Tozowanah
B.Sc. (Hons.) Dissertation "The Elastomer Test Machine", University of Wales Bangor, 1991.

Elastomer Test Machine
structure

reed switches
with adjustable
position within
table travel

dummy cylinder

piston attached
to table

sample

linear table
movement
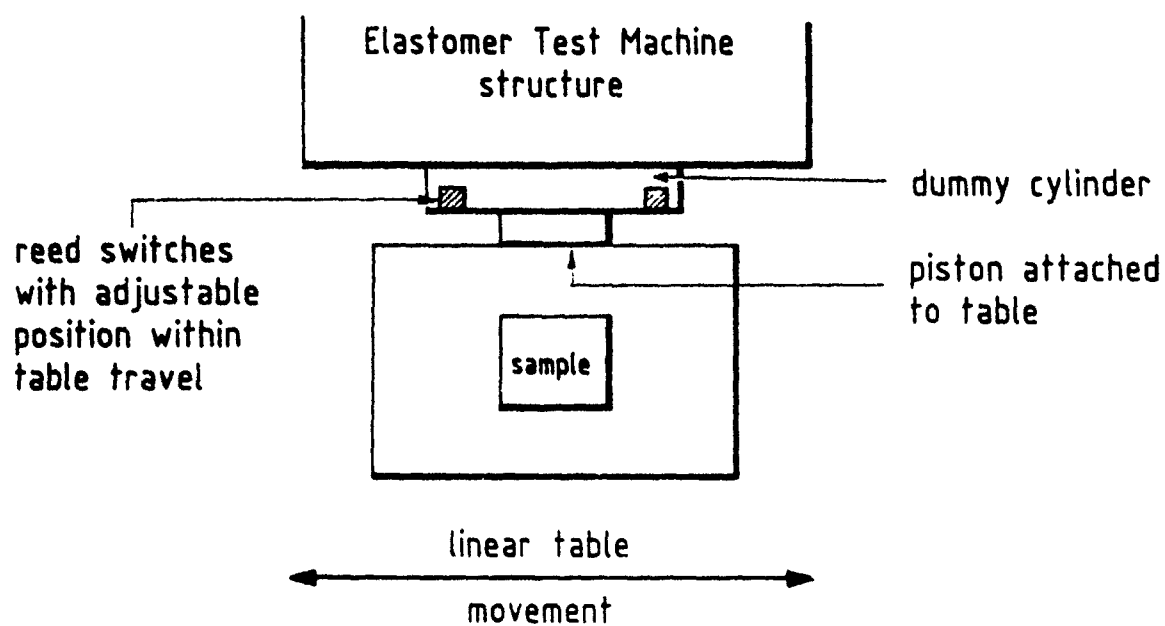
Fig. 1. Ram stroke / linear table coordination.

℄ of ram

load cell
( vertical impact )

load cells
(horizontal force)
axis of load cells
subminiature model
LFH-71 range 0-500 lbs.

pivot centre

tool bit

sample

equal
proportions
i.e. 1:1 ratio
will ensure
1:1 transmission of force
from sample to loadcell

linear movement
of sample
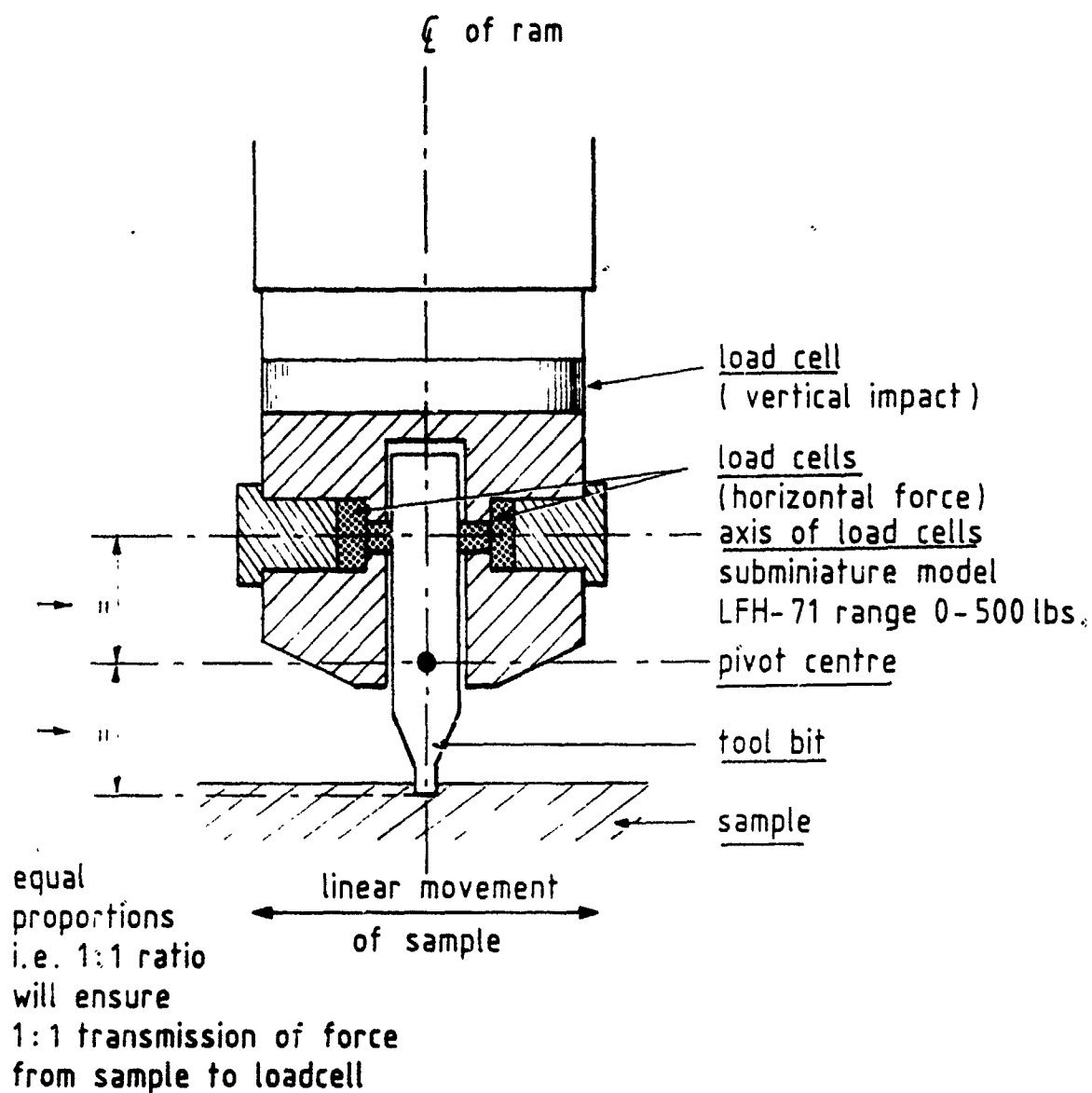
Fig. 2. Configuration of 3 load cell assembly
for sample load monitoring.
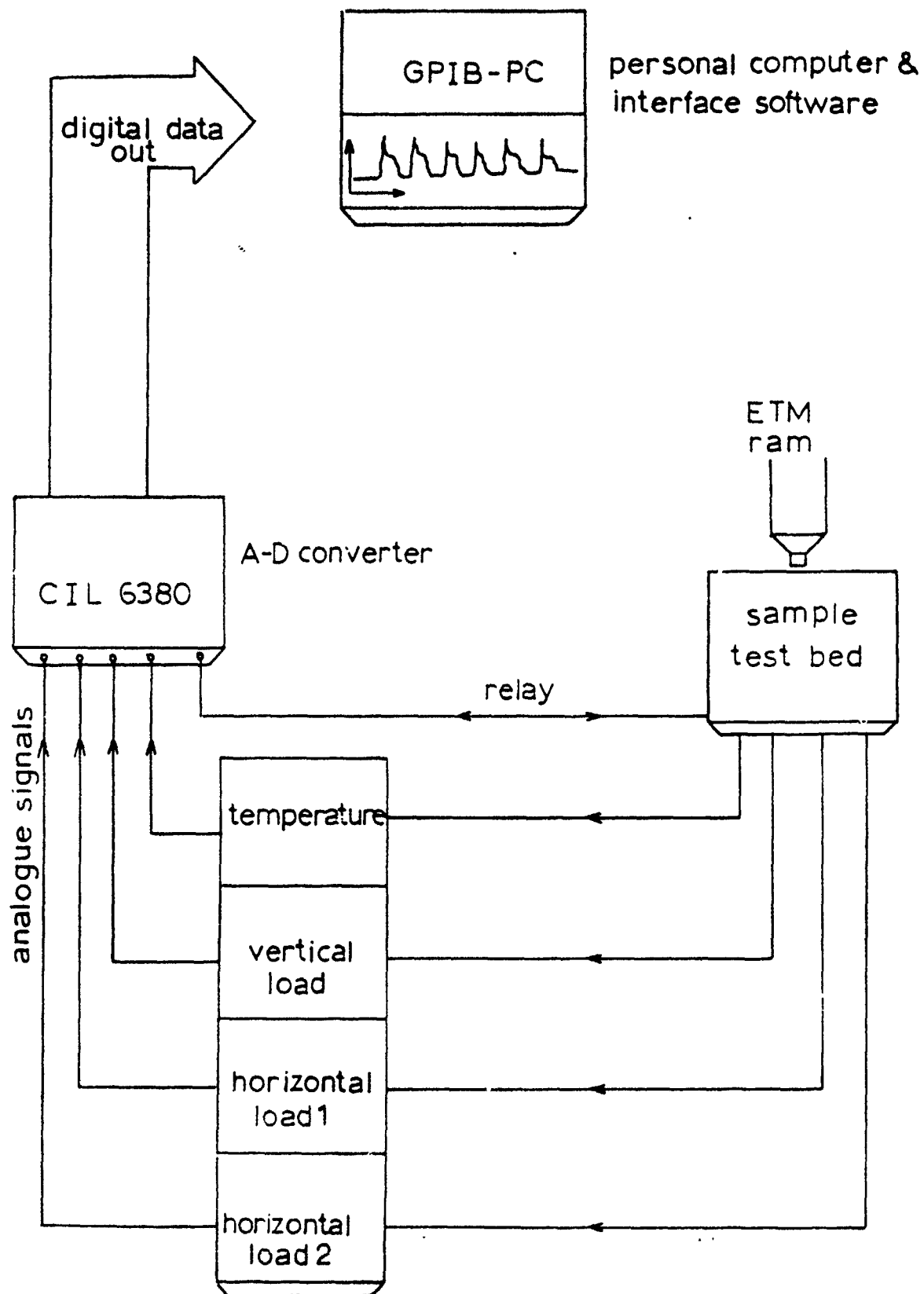
Fig. 3. ETM signal collection, logging and display.

Sample : 15 TPU
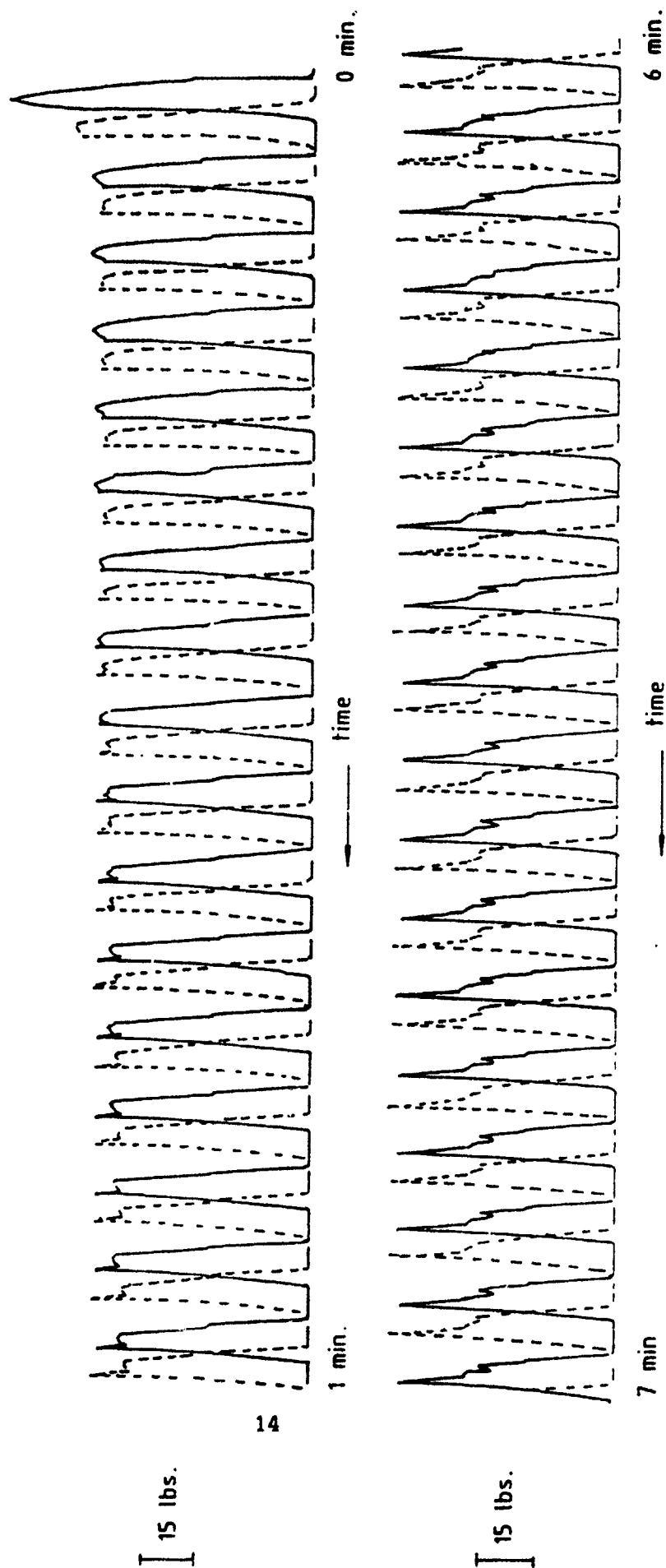


time

0 min.

1 min.

14

15 lbs.

time

6 min.

7 min.

15 lbs.

———— = left side load cell          - - - - = right side load cell

Fig. 4   Chart recorder output for impact loading in the Linear mode 2. for sample 15 TPU.

14

Sample : MB 2690

0 min.

time

1 min.

6 min.

time

7 min.
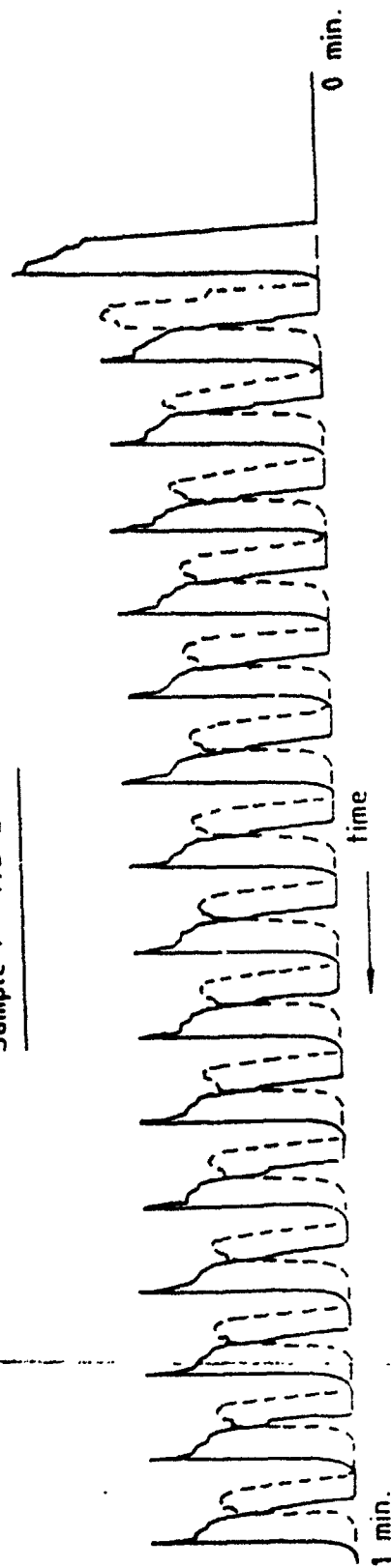
15 lbs.

15 lbs.
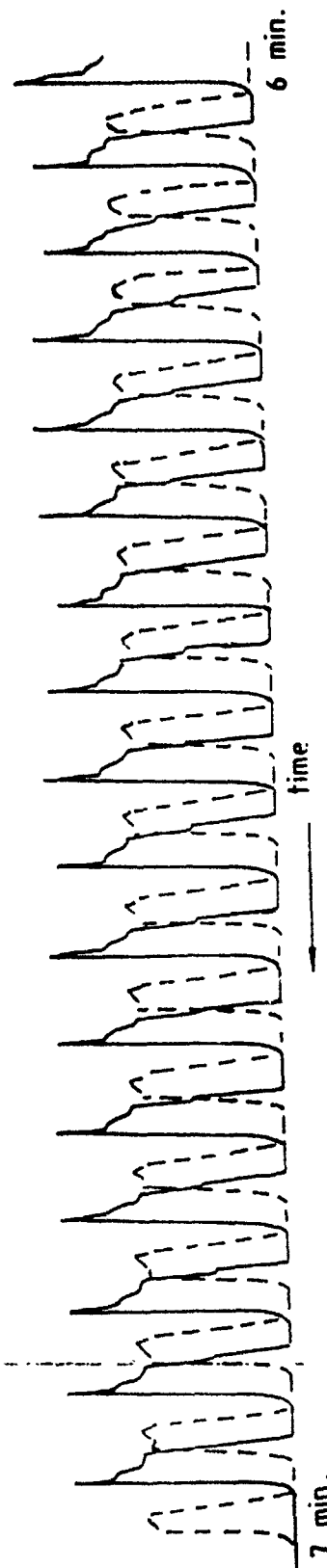
————— = left side load cell     - - - - - = right side load cell

Fig.5 . Chart recorder output for impact loading in the Linear mode 2 for sample MB 2690

Sample :  15 TP – 14 AX
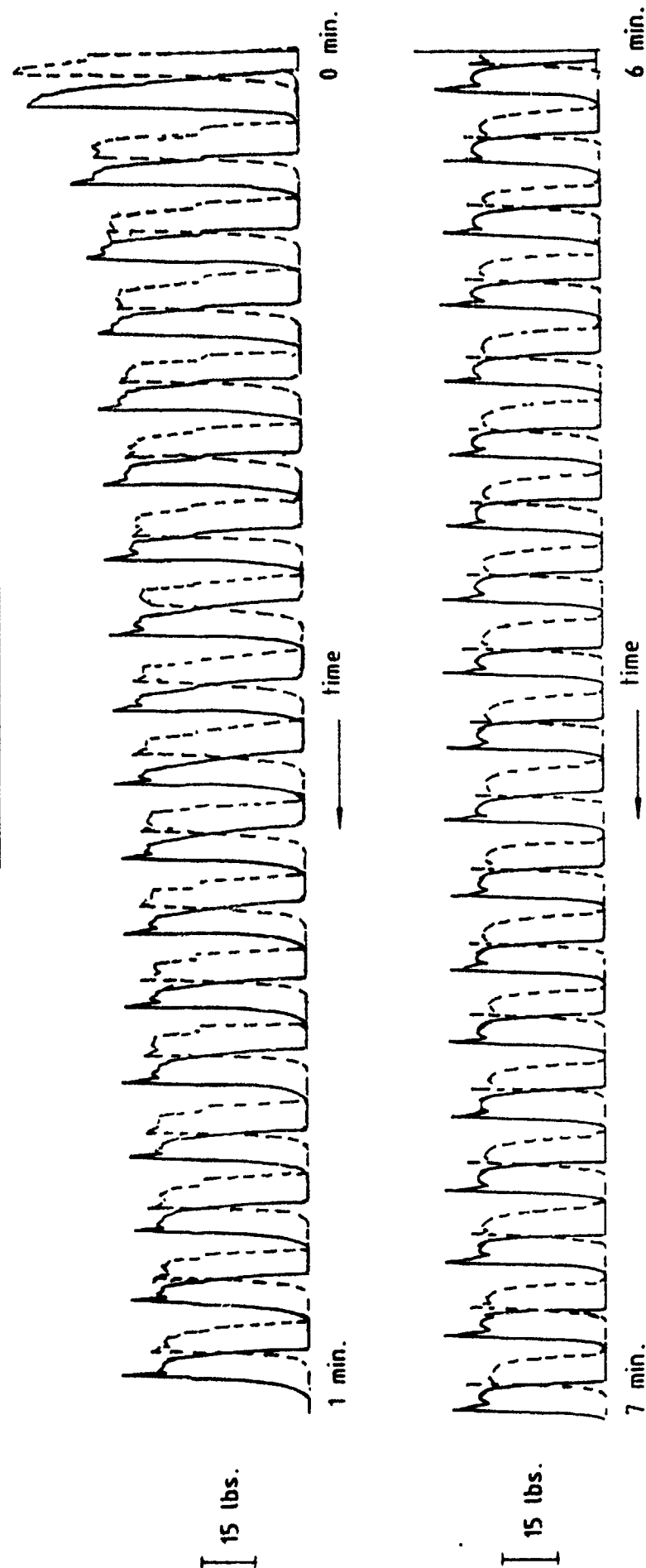


Fig. 6.  Chart recorder output for impact loading in the Linear mode 2 for sample 15 TP – 14 AX

————— = left side load cell          ------- = right side load cell

time

16
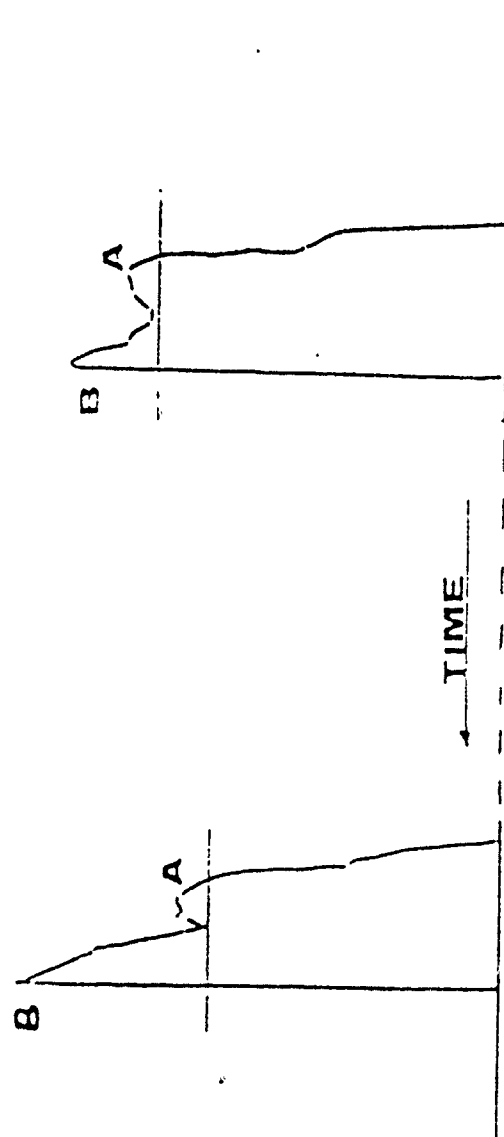
Fig 7 Impact trace (recorded) for a compliant material
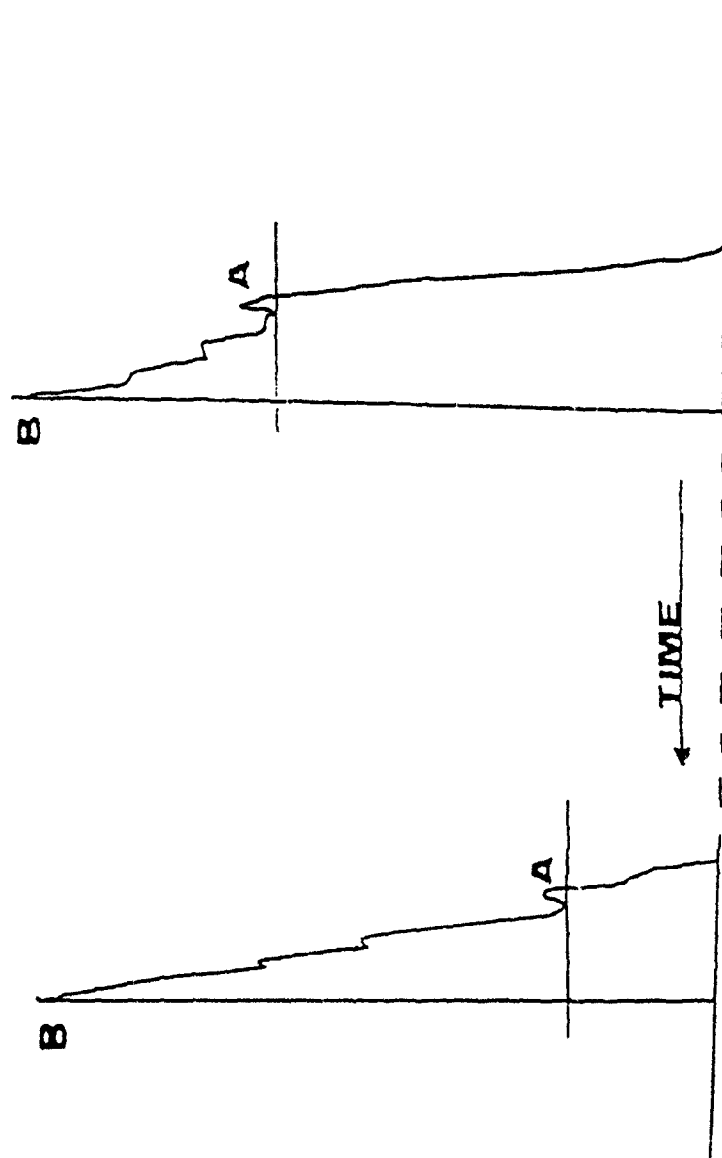
Fig. 8. Impact trace (recorded) for a hard elastomer material.
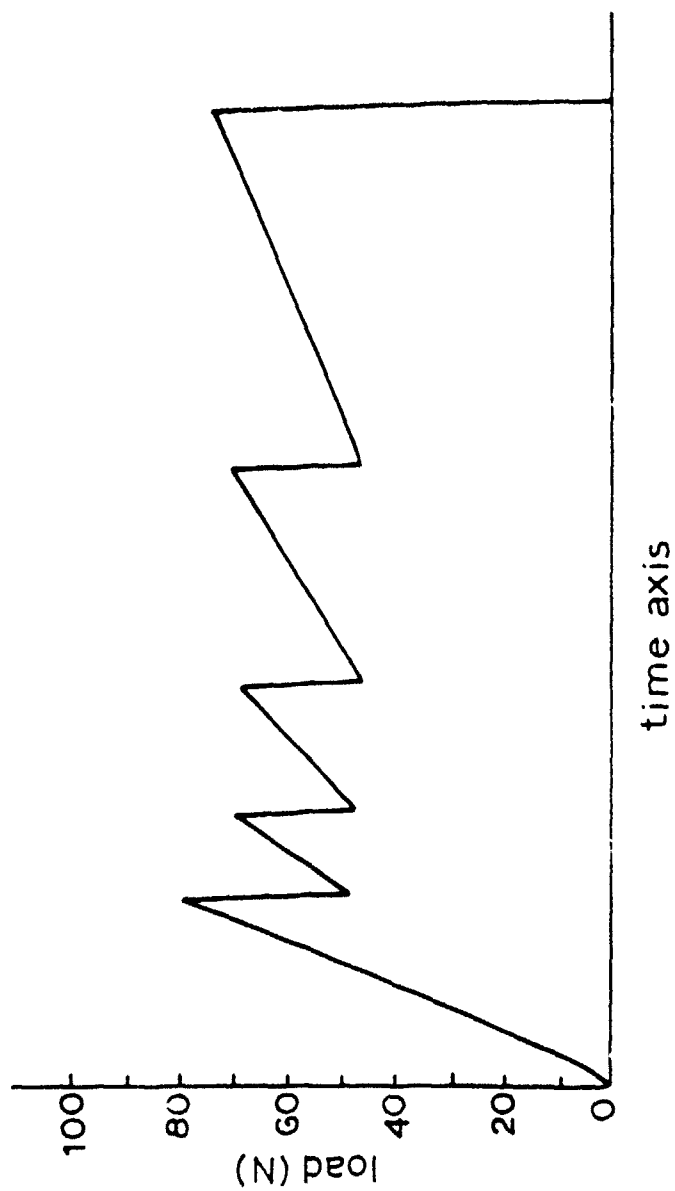
Fig.9 . A typical load-time curve for an epoxy during stick-slip crack propagation

## ROTATIONAL MODE
### RAM LOAD VARIATION



LOAD (lbs) vs TIME (MINUTES)
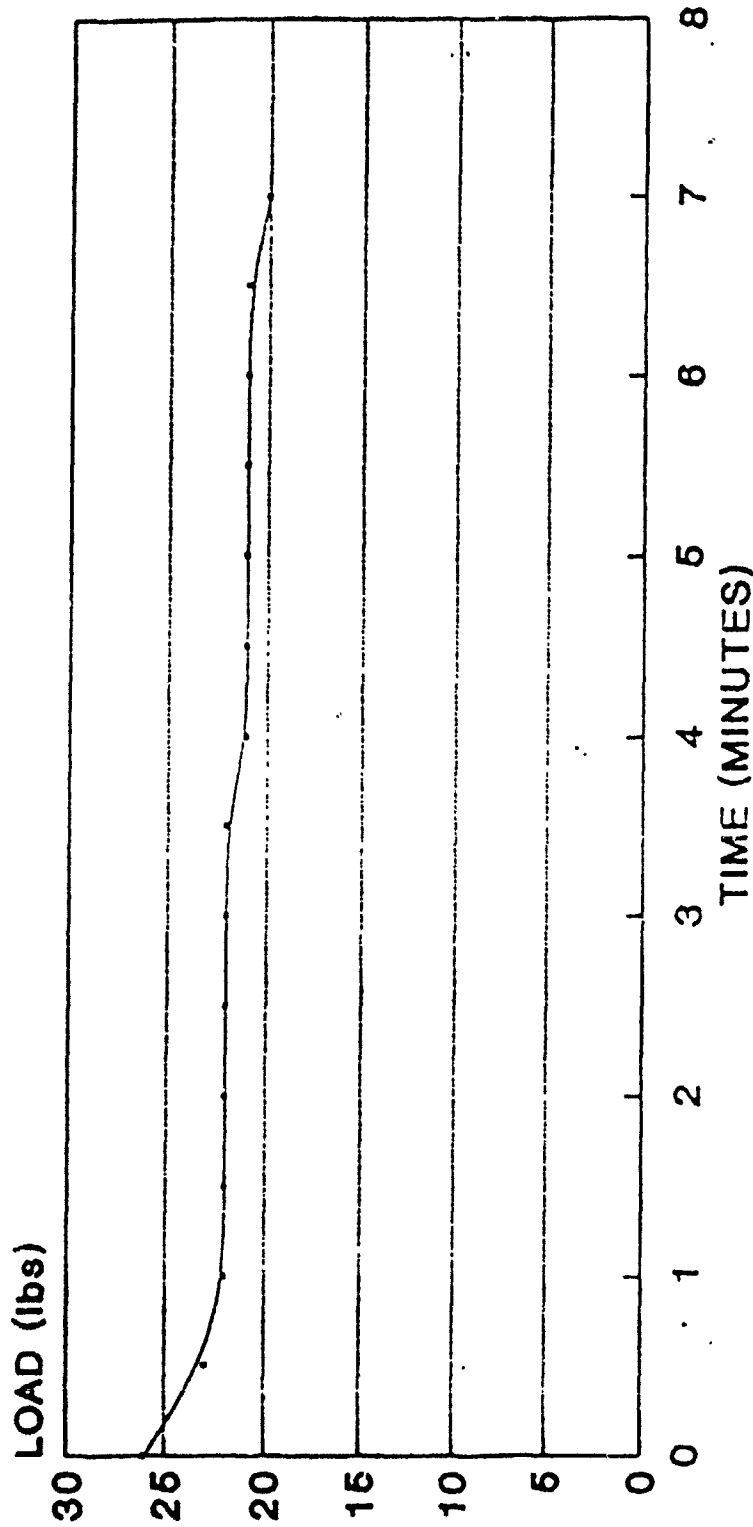
U.S.NAVY SAMPLE

37721C

Fig.10. Ram load variation with time
for sample 37721C

WEIGHT LOSS:=0.03g

# ROTATIONAL MODE
## RAM LOAD VARIATION



**LOAD (lbs)**

**TIME (MINUTES)**
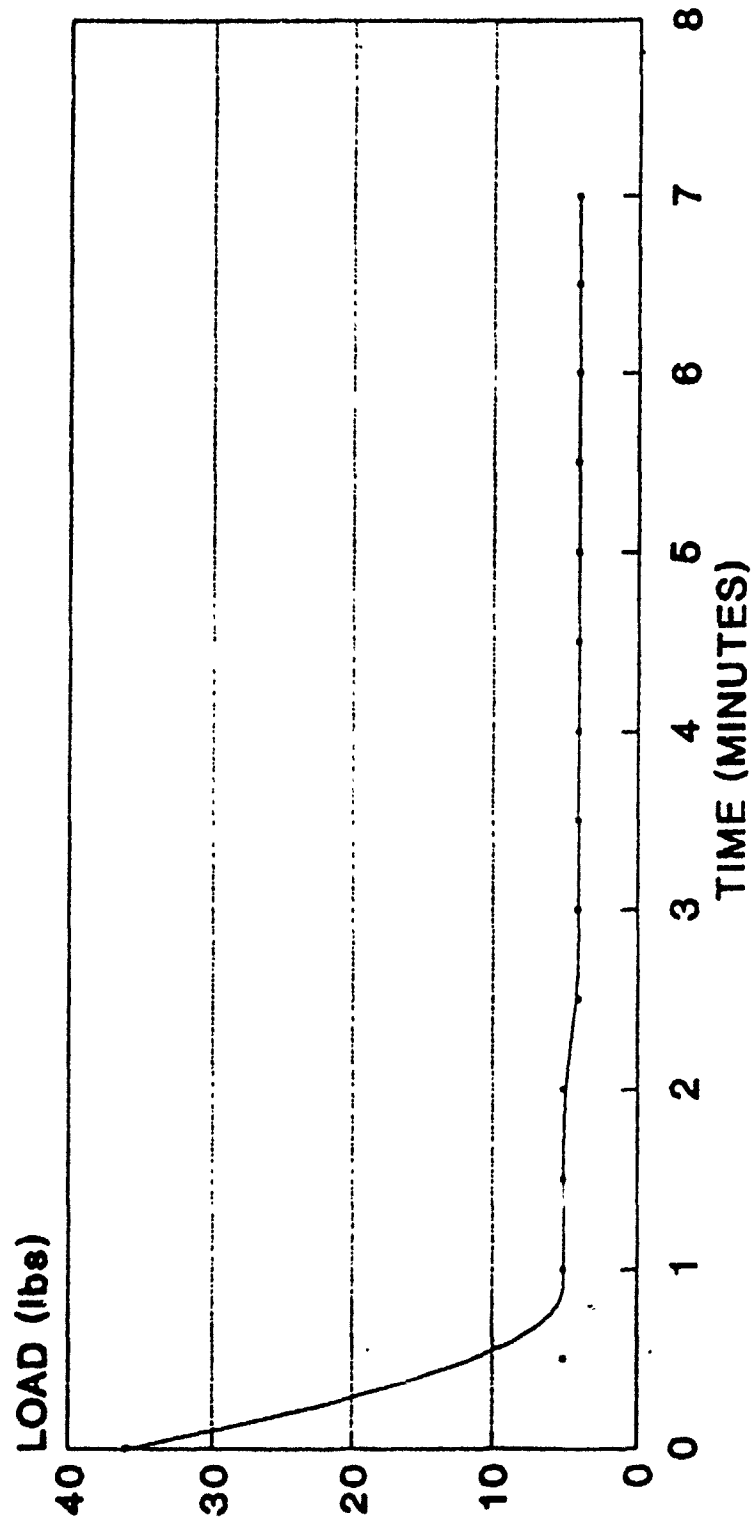
U.S.NAVY SAMPLE

POLYUR'N (NSWC 17)

Fig.11. Ram load variation with time
for sample NSWC 17

**WEIGHT LOSS:=0.31g**

# Table 1

## ORDER OF HARDNESS:-ARMY BATCH OF SAMPLES

| | SAMPLE | BREAK-IN LOAD (lb) |
|---|---|---|
| 1. | A7-MOCA | 13.0 (softest) |
| 2. | F-242 | 19.5 |
| 3. | LD.4827-5E | 30.5 |
| 4. | A8-MOCA | 32.5 |
| 5. | 150TR15 | 34.3 |
| 6. | 15NAT57 | 35.3 |
| 7. | MB2680 | 42.5 |
| 8. | 15NAT1 | 53.0 |
| 9. | AM.CYAN.8569 | 57.5 |
| 10. | 15NSP33 | 58.8 |
| 11. | 15SBR26 | 60.8 |
| 12. | 0001AG | 61.5 |
| 13. | MB-2690 | 63.3 |
| 14. | 15NAT22A | 64.2 |
| 15. | 0001AD | 67.5 |
| 16. | 0001AL | 75.0 |
| 17. | 15TP14AX | 81.5 |
| 18. | LD.4869-33A | 83.1 |
| 19. | 15NAT60 | 86.1 |
| 20. | CAYTUR21 | 87.2 |
| 21. | 15NSP2A | 87.5 |
| 22. | 15TPU | 90.5 |
| 23. | 0001AC | 99.6 |
| 24. | 15NSP34 | 103.5 |
| 25. | CAYTUR31 | 106.0 |
| 26. | 0001AK | 107.9 |
| 27. | 0001AF | 108.3 |
| 28. | STEIN.M.L83 | 108.4 |
| 29. | 15TPT | 109.7 |
| 30. | RTC.2000 | 110.7 |
| 31. | 1080-MOCA | 112.7 |
| 32. | 0001AH | 117.6 |
| 33. | 0001AA | 118.5 |
| 34. | LD.4827-5C | 123.8 |
| 35. | WR | 135.1 |
| 36. | CYAN.84-200 | 145.5 |
| 37. | AK20 | 147.0 |
| 38. | SPONGE.A.MOCA | 155.6 |
| 39. | 15TPS | 161.0 |
| 40. | LD.4655-66 | 168.0 |
| 41. | XPE20 | 171.0 |
| 42. | XPE30 | 188.4 |
| 43. | LD.4718-53 | 204.0 |
| 44. | LD.4718-22 | 207.6 |
| 45. | LD.4827-5B | 211.5 |
| 46. | XPE10 | 229.4 |
| 47. | LD.EP4933-75 | 234.9 |
| 48. | LD.4608-62 | 278.6 |
| 49. | LD.4608-60 | 288.0 (hardest) |

# Table 2

## RESULTS:-LOAD DEPRECIATION (ARMY BATCH) LINEAR 1 MODE

| | SAMPLE NAME | INITIAL LOAD POUNDS | FINAL LOAD POUNDS | DEP. POUNDS | DEP. % |
|---|---|---|---|---|---|
| 1. | MB-2690 | 38.0 | 39.3 | -1.3 | * |
| 2. | A7-MOCA | 11.0 | 12.0 | -1.0 | * |
| 3. | F-242 | 16.0 | 17.0 | -1.0 | * |
| 4. | A8-MOCA | 18.6 | 18.3 | 0.3 | 1.60 |
| 5. | AM.CYAN.8569 | 31.9 | 28.5 | 3.4 | 10.66 |
| 6. | XPE30 | 105.7 | 94.0 | 11.7 | 11.07 |
| 7. | CATUR31 | 61.5 | 54.2 | 7.3 | 11.95 |
| 8. | 15SBR26 | 41.9 | 36.0 | 5.9 | 14.18 |
| 9. | 15NAT1 | 34.5 | 28.5 | 6.0 | 17.39 |
| 10. | OOOAL | 45.6 | 35.5 | 10.1 | 22.15 |
| 11. | XPE20 | 107.3 | 82.5 | 21.2 | 23.11 |
| 12. | 15OTR15 | 26.7 | 20.0 | 6.7 | 25.23 |
| 13. | 1080-MOCA | 32.2 | 23.3 | 8.9 | 27.60 |
| 14. | 0001AG | 32.0 | 22.8 | 9.2 | 28.75 |
| 15. | SPONGE.A.MOCA | 72.0 | 51.0 | 21.0 | 29.20 |
| 16. | LD.EP4933-75 | 81.0 | 57.0 | 24.0 | 29.63 |
| 17. | LD.4718-53 | 86.7 | 59.3 | 27.4 | 31.66 |
| 18. | 15NAT60 | 58.5 | 39.3 | 19.2 | 32.80 |
| 19. | 15NSP34 | 66.0 | 44.0 | 22.0 | 33.33 |
| 20. | 0001AH | 76.5 | 51.0 | 25.5 | 33.33 |
| 21. | 15TP14AX | 51.4 | 33.8 | 17.6 | 34.24 |
| 22. | 15NAT57 | 26.3 | 17.3 | 9.0 | 34.29 |
| 23. | 15TPU | 62.8 | 40.5 | 22.3 | 35.46 |
| 24. | MB-2680 | 31.3 | 31.0 | 11.2 | 35.78 |
| 25. | 0001AK | 55.8 | 35.5 | 20.3 | 36.38 |
| 26. | 0001AD | 47.2 | 30.0 | 17.2 | 36.44 |
| 27. | LD.4608-62 | 106.2 | 67.5 | 38.7 | 36.44 |
| 28. | LD.4608-60 | 94.8 | 58.5 | 36.3 | 38.29 |
| 29. | AK20 | 73.3 | 45.0 | 28.3 | 38.61 |
| 30. | 0001AA | 64.9 | 39.5 | 25.4 | 39.14 |
| 31. | RTC.2000 | 22.5 | 13.5 | 9.0 | 40.00 |
| 32. | 15NSP2A | 57.9 | 34.3 | 23.6 | 40.76 |
| 33. | 0001AC | 60.6 | 35.6 | 25.0 | 41.23 |
| 34. | LD.4689-33A | 36.8 | 21.0 | 15.8 | 42.94 |
| 35. | LD.4655-66 | 88.3 | 49.5 | 38.8 | 43.94 |
| 36. | 15NAT22A | 45.4 | 25.0 | 20.4 | 44.93 |
| 37. | 15TPS | 66.0 | 36.3 | 29.7 | 45.00 |
| 38. | LD.4718-22 | 83.8 | 46.0 | 37.8 | 45.11 |
| 39. | 0001AF | 60.4 | 33.0 | 27.4 | 45.36 |
| 40. | STEIN.M.L-83 | 59.4 | 32.4 | 27.0 | 45.45 |
| 41. | LD.4827-5B | 53.0 | 28.5 | 24.5 | 46.23 |
| 42. | 15TPT | 59.0 | 31.0 | 28.0 | 47.46 |
| 43. | LD.4827-5C | 59.8 | 31.0 | 28.8 | 48.16 |
| 44. | 0001AC | 61.7 | 31.8 | 29.9 | 48.54 |
| 45. | CYAN.84-200 | 88.0 | 45.0 | 43.0 | 48.86 |
| 46. | CAYTUR21 | 51.9 | 26.0 | 25.9 | 49.90 |
| 47. | WR | 89.8 | 42.6 | 47.2 | 52.52 |
| 48. | XPE10 | 146.6 | 51.2 | 95.4 | 65.08 |

*   *no positive deterioration.*

# Table 3

## WEIGHT LOSS (ARMY SAMPLES) IN LINEAR 1 MODE

| SAMPLE NAME | INITIAL MASS GRAMMES | FINAL MASS GRAMMES | LOSS GRAMMES |
|---|---|---|---|
| 1. F 242 | 69.97 | 69.97 | 0.00 |
| 2. A8 MOCA | 73.93 | 73.93 | 0.00 |
| 3. AM CYAN 8569 | 74.67 | 74.67 | 0.00 |
| 4. MB 2690 | 68.93 | 68.92 | 0.01 |
| 5. 15 TP14 AX | 62.50 | 62.47 | 0.03 |
| 6. 15 SBR 26 | 61.50 | 61.46 | 0.04 |
| 7. 0001AD | 70.83 | 70.70 | 0.04 |
| 8. 0001AL | 67.93 | 67.89 | 0.04 |
| 9. LD 4655 66 | 64.28 | 64.23 | 0.05 |
| 10. 15 NAT 57 | 52.77 | 52.71 | 0.06 |
| 11. 15 NAT 22A | 68.52 | 68.45 | 0.07 |
| 12. 0001AK | 70.37 | 70.30 | 0.07 |
| 13. LD 4827 5B | 66.11 | 66.04 | 0.07 |
| 14. 15 NSP 2A | 73.37 | 73.29 | 0.08 |
| 15. 15 TPT | 70.31 | 70.23 | 0.08 |
| 16. 15 OTR 15 | 65.34 | 65.25 | 0.09 |
| 17. 0001AA | 74.42 | 74.33 | 0.09 |
| 18. 15 TPU | 70.24 | 70.15 | 0.09 |
| 19. 15 NAT 1 | 65.36 | 65.26 | 0.10 |
| 20. CAYTUR 31 | 64.41 | 62.31 | 0.10 |
| 21. 15 NSP 34 | 73.19 | 73.09 | 0.10 |
| 22. WR | 81.24 | 81.14 | 0.10 |
| 23. 15 TPS | 70.74 | 70.63 | 0.11 |
| 24. XPE20 | 65.57 | 65.46 | 0.11 |
| 25. 0001AC | 76.02 | 75.91 | 0.11 |
| 26. LD EP4933 75 | 66.71 | 66.59 | 0.12 |
| 27. CAYTUR 21 | 62.99 | 62.87 | 0.12 |
| 28. 15 NSP 33 | 69.46 | 69.34 | 0.12 |
| 29. LD 4718 53 | 64.13 | 64.00 | 0.13 |
| 30. 0001AG | 71.60 | 71.46 | 0.14 |
| 31. 0001AF | 76.35 | 76.21 | 0.14 |
| 32. 0001AH | 74.94 | 74.79 | 0.15 |
| 33. 15 NAT 60 | 65.52 | 65.37 | 0.15 |
| 34. MB 2680 | 64.32 | 64.16 | 0.16 |
| 35. CYAN 84 200 | 64.34 | 64.17 | 0.17 |
| 36. STEIN L83 | 63.72 | 63.55 | 0.17 |
| 37. XPE30 | 64.98 | 64.78 | 0.20 |
| 38. LD 4827 5D | 64.90 | 64.70 | 0.20 |
| 39. 80 5 MOCA | 63.60 | 63.39 | 0.21 |
| 40. AK20 | 64.04 | 63.84 | 0.22 |
| 41. LD 4608 62 | 67.79 | 67.56 | 0.23 |
| 42. LD 4827 5C | 63.41 | 63.17 | 0.24 |
| 43. XPE10 | 63.95 | 63.71 | 0.24 |
| 44. LD 4718 22 | 72.09 | 71.84 | 0.25 |
| 45. A7 MOCA | 81.22 | 80.93 | 0.29 |
| 46. LD 4689 33A | 65.74 | 65.43 | 0.31 |
| 47. LD 4608 60 | 67.04 | 66.71 | 0.33 |
| 48. LD 4827 5E | 64.89 | 64.55 | 0.34 |
| 49. 1080 MOCA | 62.95 | 62.58 | 0.37 |
| 50. RTC 2000 | 57.13 | 56.75 | 0.38 |
| 51. A.MOCA | 75.20 | 74.77 | 0.43 |

# Table 4

## RESULTS FOR ARMY SAMPLES LINEAR 2 MODE

| SAMPLE | WEIGHT LOSS (g) | LOAD DEPRECIATION (%) | |
|---|---|---|---|
| MB 2590 | 0.01 | 0 | |
| 15 NSP 34 | 0.04 | 16 | |
| 15 NAT 57 | 0.05 | 15.3 | |
| 15 NSP 2A | 0.05 | 15.4 | |
| 15 OTR 15 | 0.06 | 1.1 | |
| 15 NAT 60 | 0.06 | 14.8 | |
| 15 SBR 26 | 0.07 | 10.3 | |
| 0001AL | 0.07 | 14.7 | |
| 15 NAT 25A | 0.07 | 21.2 | |
| F 242 | 0.08 | -21.7 | * |
| PL 1500 | 0.08 | 24.4 | |
| 0001AD | 0.09 | 14.6 | |
| 15 TPU | 0.09 | 19.1 | |
| WR 1 | 0.09 | 21 | |
| 0001AL | 0.10 | 12.7 | |
| 15 NSP 33 | 0.10 | 16.8 | |
| 0001AK | 0.10 | 17.9 | |
| PL 1000 | 0.10 | 19.2 | |
| 15 NAT 1 | 0.10 | 22 | |
| 0001AC | 0.11 | 10 | |
| 15 TP14 AX | 0.11 | 15.3 | |
| 15 TPT | 0.11 | 20.9 | |
| 15 TPS | 0.11 | 31.8 | |
| 15 NAT 22A | 0.12 | 22.4 | |
| 0001AF | 0.13 | 13.1 | |
| 0001AG | 0.13 | 19.7 | |
| LD 4718 53 | 0.14 | 20.5 | |
| 0001AA | 0.16 | 25.9 | |
| CAYTUR 21 | 0.17 | 17.3 | |
| LD 4608 60 | 0.17 | 14.6 | |
| A8 MOCA | 0.18 | - 3.7 | * |
| EP 4933 75 | 0.19 | 13.2 | |
| LD 4608 62 | 0.19 | 14.6 | |
| 8569 | 0.23 | - 1.5 | * |
| 0001AH | 0.28 | 48 | |
| A.MOCA | 0.28 | 52.9 | |
| LD 4655 66 | 0.29 | 25 | |
| PL 2000 | 0.29 | 37.9 | |
| LD 4827 5C | 0.30 | 26.8 | |
| LD 4718 22 | 0.31 | 17.9 | |
| CAYTUR 31 | 0.34 | 26.2 | |
| 80 5 MOCA | 0.34 | 43.8 | |
| STEIN L83 | 0.37 | 19.2 | |
| XPE 10 | 0.42 | 10 | |
| AK20 | 0.44 | 20.9 | |
| XPE20 | 0.47 | 26.3 | |
| XPE30 | 0.53 | 9.3 | |
| LD 4689 33A | 0.53 | 32.8 | |
| RTC 2000 | 0.53 | 45.1 | |
| A7 MOCA | 0.54 | 14.9 | |
| CYAN 84 200 | 0.59 | 81.2 | |
| LD 4827 5E | 0.63 | 57.1 | |
| MB 2680 | 0.63 | 41.7 | |
| 1080 MOCA | 0.69 | 47.3 | |

\*   NO POSITIVE DETERIORATION

## Table 5

### RESULTS SHOWING SAMPLES ORDERED IN TERMS OF LOAD DEPRECIATION FOR LINEAR 2 MODE

| SAMPLE | DEPRECIATION (%) |
|---|---|
| 1. F 242 | - 21.7 |
| 2. A8 MOCA | - 3.7 |
| 3. 8569 | - 1.5 |
| 4. MB 2690 | 0 |
| 5. 15 OTR 15 | 1.1 |
| 6. XPE30 | 9.3 |
| 7. 0001AC | 10 |
| 8. XPE10 | 10 |
| 9. 15 SBR 26 | 10.3 |
| 10. 0001AL | 12.7 |
| 11. 0001AF | 13.1 |
| 12. EP 4933 75 | 13.2 |
| 13. 0001AD | 14.6 |
| 14. LD 4608 60 | 14.6 |
| 15. LD 4608 62 | 14.6 |
| 16. 0001AL | 14.7 |
| 17. 15 NAT 60 | 14.8 |
| 18. A7 MOCA | 14.9 |
| 19. 15 NAT 57 | 15.3 |
| 20. 15 TP14 AX | 15.3 |
| 21. 15 NSP 2A | 15.4 |
| 22. 15 NSP 34 | 16 |
| 23. 15 NSP 33 | 16.9 |
| 24. CAYTUR 21 | 17.3 |
| 25. 0001AK | 17.9 |
| 26. LD 4718 22 | 17.9 |
| 27. 15 TPU | 19.1 |
| 28. PL 1000 | 19.2 |
| 29. STEIN L83 | 19.2 |
| 30. 0001AG | 19.7 |
| 31. LD 4718 53 | 20.5 |
| 32. 15 TPT | 20.9 |
| 33. AK20 | 20.9 |
| 34. WR 1 | 21 |
| 35. 15 NAT 25A | 21.2 |
| 36. 15 NAT 1 | 22 |
| 37. 15 NAT 22A | 22.4 |
| 38. PL 1500 | 24.4 |
| 39. LD 4655 66 | 25 |
| 40. 0001AA | 25.9 |
| 41. CAYTUR 31 | 26.2 |
| 42. XPE20 | 26.3 |
| 43. LD 4D27 5C | 26.8 |
| 44. 15 TPS | 31.8 |
| 45. LD 4689 33A | 32.8 |
| 46. PL 2000 | 37.9 |
| 47. MB 2680 | 41.7 |
| 48. 85 5 MOCA | 43.8 |
| 49. RTC 2000 | 45.1 |
| 50. 1080 MOCA | 47.3 |
| 51. 0001AH | 48 |
| 52. A.MOCA | 52.9 |
| 53. LD 4627 5E | 57.1 |
| 54. CYAN 84 200 | 81.2 |

### TABLE 6. ETM LINEAR 2 MODE RESULTS (333K)

|                    | NBR-12 | TP-14AY | 89EV110 | 58R74 | 37721C | POLYURETHANE |
|--------------------|--------|---------|---------|-------|--------|--------------|
| DEP.(%)            | .35.0  | 18.0    | 36.0    | 15.0  | 5.4    | 45.6         |
| WEIGHT LOSS (g)    | 0.10   | 0.11    | 0.24    | 0.06  | 0.05   | 0.36         |
| HARDNESS (lbs)     | 65.0   | 55.0    | 103.0   | 63.0  | 45.0   | 35.0         |
| DENSITY (293K)     | 1.13   | 1.15    | 1.13    | 1.15  | 1.13   | 1.10         |

### TABLE 7. ETM LINEAR 1 MODE RESULTS (333K)

|                    | NBR-12 | TP-14AY | 89EV110 | 58R74 | 37721C | POLYURETHANE |
|--------------------|--------|---------|---------|-------|--------|--------------|
| DEP.(%)            | 16.3   | 2.7     | 48.7    | 32.1  | 25.7   | 69.7         |
| WEIGHT LOSS (g)    | 0.04   | 0.08    | 0.04    | 0.08  | 0.04   | 0.23         |

### TABLE 8. ETM ROTATIONAL MODE RESULTS (333K)

|                    | NBR-12 | TP-14AY | 89EV110 | 58R74 | 37721C | POLYURETHANE |
|--------------------|--------|---------|---------|-------|--------|--------------|
| DEP.(%)            | 51.4   | 17.6    | 81.5    | 34.1  | 23.1   | 89.0         |
| WEIGHT LOSS (g)    | 0.14   | 0.08    | 0.07    | 0.02  | 0.03   | 0.31         |

## TABLE 9. LINEAR MODE EROSION RESULTS (333K)

| Sample | Failure Mode | Rating |
|---|---|---|
| 37721C | Debris displacement after 2.5 minutes. Fine black particles. Light damage area. Damage zone 22mmx4.5mm. | Good |
| 58R74 | Scraping of surface leading to material loss after 30 seconds. Similar wear texture to 37721C. Damage zone 22mmx4.4mm. | Good |
| 15TP-14AX | Little material lost. High resilience. Low damage. Smooth wear track 21mmx4mm. | Good |
| NBR-12 | Chips of debris lost. Tear flaps visible. Some debris adhesion. Damage zone 18mmx5mm. | Fair |
| 89EV110 | Small chunks of debris with adhesion. Damage zone 17mmx6mm. | Fair |
| NSWC 17 | Immediate danmage. large chips of transluscent debris. Deep trough cut by tool. Damage area 26mmx5.5mm. | Poor |

## TABLE 10. ROTATIONAL MODE RESULTS (333K)

| Sample | Failure Mode | Rating |
|---|---|---|
| 37721C | Shallow circular track surrounding central plug. minimum amount of material loss. | Good |
| 58R74 | Circular track as for 37721C. Fine particles of material lost. | Good |
| 15TP-14AX | Spiral cuts in the circular groove around small plug. | Good |
| NBR-12 | Stringy black debris. Familiar wear pattern with raised central plug. | Fair |
| 89EV110 | Small pieces of material removed. More notable damage than other black rubber samples. | Fair |
| NSWC 17 | Immediate damage onset. Jelly-like pieces of debris. Large hole excavated. central projection completely removed. | Poor |